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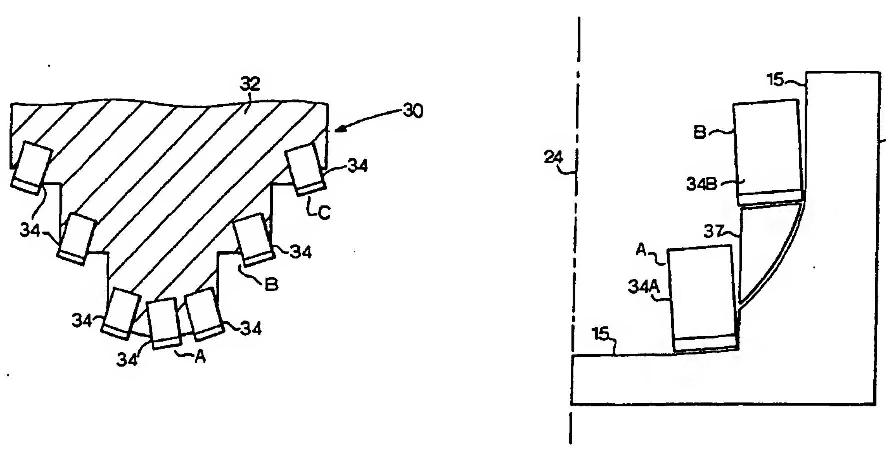
(54) Title: SYSTEM FOR ROTARY-PERCUSSION DRILLING IN AN EARTH FORMATION



(57) Abstract: A drilling system for drilling a borehole in an earth formation, comprising a drill string having a central longitudinal (24) axis and being provided with a drill bit (30) having a bottom surface including a plurality of cutters (34) arranged so that said bottom surface has an envelope of a stepped profile in radial direction. First drive means is provided for rotating the drill bit in the borehole so as to induce a scraping movement of the cutters along the borehole bottom (15) and second drive means is provided fo r inducing a longitudinal reciprocal movement of the drill bit in the borehole so as to induce the cutters to exert a percussion force to the borehole bottom.

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SYSTEM FOR ROTARY-PERCUSSION DRILLING IN AN EARTH FORMATION

The invention relates to a drilling system for drilling a borehole in an earth formation using a drill string having a central longitudinal axis and provided with a drill bit having a bottom surface including a plurality of cutters. Generally there are two basic types of drilling systems, one being the rotational type whereby the drill bit is provided with relative sharp cutters which scrape along the borehole bottom, and the other being the percussion type which generally includes a hammer mechanism that delivers mechanical impacts to the rock formation via the drill bit.

Drill bits traditionally used in percussion drilling have hemispherical cutters usually made of a hard metal such as Tungsten Carbide, which may be coated with a thin diamond layer. Such cutters are generally referred to as Polycrystalline Diamond Enhanced cutters.

It has been experienced that drilling speed with either percussion type drilling systems or rotational type drilling systems is generally low for drilling into very hard rock material. Rotational type systems have the drawback that the scraping action is insufficient for such to rock materials, and percussion type systems lack durability.

It is therefore an object of the invention to provided an improved drilling system which enables increased drilling speed.

In accordance with the invention there is provided a drilling system for drilling a borehole in an earth formation, comprising:

- a drill string having a central longitudinal axis and being provided with a drill bit having a bottom surface including a plurality of cutters arranged so that said bottom surface has an envelope of a stepped profile in radial direction;
- first drive means for rotating the drill bit in the borehole so as to induce a scraping movement of the cutters along the borehole bottom, and
- second drive means for inducing a longitudinal reciprocal movement of the drill bit in the borehole so as to induce the cutters to exert a percussion force to the borehole bottom.

It is thereby achieved that the stepped profile of the bit bottom envelope creates a stepped profile in the borehole bottom as a result of the rotational movement of the drill bit. The "steps" of the stepped profile form edges which are broken off from the borehole bottom by virtue of the percussion action of the drill bit against the borehole bottom. In this manner relatively large pieces of rock can be removed from the borehole bottom, resulting in increased drilling speed.

Suitably the cutters are arranged in a plurality of circular rows of mutually different diameters, and wherein the top surfaces of cutters in the same row extend at substantially equal axial positions.

Further, it is preferred that the cutters in a first said row and the cutters in a second said row adjacent to the first row have top surfaces at mutually different axial position.

In a preferred embodiment said bottom surface of the drill bit has a convex shape.

Preferably the cutters are Polycrystalline Diamond Compact (PDC) cutter including a shank made of a base

material and a top layer made of a poly-crystalline diamond material.

In order to efficiently remove the drill cuttings, it is preferred that the top surface of each cutter has a primary inclination relative to the tangential velocity component of the cutter, the primary inclination being such that the top surface pushes drill cuttings in the direction of rotational movement of the cutter.

Drill cuttings removal is further enhanced if the top surface has a secondary inclination relative to the radial direction of the cutter, the secondary inclination being such that the top surface pushes drill cuttings from the rock formation in radially outward or radially inward direction.

Suitably the cutter has a back-rake angle of less than 90°, wherein the back-rake angle is defined as the angle between the projection of a line perpendicular to said top surface on a plane defined by the longitudinal direction of the drill string and the direction of the tangential velocity component of the cutter, and a plane perpendicular to said longitudinal direction.

Preferably the back-rake is between 30° and 90°, and more preferably between 30° and 75°.

Furthermore, it is preferred that the cutter has a side-angle of less than 90°, wherein the side-angle is defined as the angle between the projection of said line perpendicular to the top surface on said plane perpendicular to the longitudinal direction, and said plane defined by the longitudinal direction and the direction of the tangential velocity component of the cutter.

The invention will be described hereinafter in more detail and by way of example, with reference to the accompanying drawings in which

Fig. 1 schematically shows a bottom view of a first embodiment of a drill bit for use in the method of the invention;

Fig. 2 schematically shows a side view of a cutter of the drill bit of Fig. 1;

Fig. 3 schematically shows a perspective view of the cutter of Fig. 2, for two different positions of the cutter on the borehole;

Fig. 4 schematically shows a bottom view of a second embodiment of a drill bit for use in the method of the invention;

Fig. 5 schematically shows a longitudinal section of the drill bit of Fig. 4;

Fig. 6 schematically shows two cutters of the second drill bit;

Fig. 7 schematically shows a perspective view of a cutter of a drill bit for use in the method of the invention;

Fig. 8 schematically shows a top view (i.e. a view towards the borehole bottom) of a first arrangement of the cutter of Fig. 7;

Fig. 9 schematically shows a top view (i.e. a view towards the borehole bottom) of a second arrangement of the cutter of Fig. 7;

Fig. 10A schematically shows a bottom view of a third embodiment of a drill bit for use in the method of the invention; and

Fig. 10B schematically shows a longitudinal section of a borehole bottom as drilled with the drill bit of Fig. 10A.

In the Figures like reference numerals relate to like components.

Referring to Fig. 1 there is shown a first embodiment of a drill bit 1 having a bit body 2 provided with a plurality of cutters 4 mutually spaced along the bottom face of the drill bit 1. For the sake of clarity, not each cutter has been indicated by a reference numeral. The bit body 2 is furthermore provided with a number of nozzles 6 and waterways 8 for drilling fluid.

As shown in Fig. 2, each cutter 4 has a shank 10 made of a hard base material such as Tungsten Carbide and a top layer 12 made of a poly-crystalline diamond material. Such cutters are commonly referred to as PDC (Poly-crystalline Diamond Compact) cutters. The top layer 12 has a top surface 14 arranged to contact the borehole bottom 15 during drilling. The cutter 4 is fixed to the bit body at a back-rake angle α of about 70°, wherein the back-rake angle α is defined as the angle between the projection of a line 16 which extends perpendicular to said top surface 14, on a plane defined by the longitudinal axis 24 of the drill bit 1 and the direction of the tangential velocity component 18 of the cutter 4, and a plane 17 perpendicular to the longitudinal direction of the drill bit 1. The angle α can also be defined as a primary inclination of the top surface 14 relative to the tangential velocity component 18 of the cutter, the primary inclination being such that the top surface pushes drill cuttings in the direction of rotational movement of the cutter. In Fig. 2, the combined movement of the cutter 4 as a result of rotational movement and percussion movement of the drill bit 1, is indicated by arrows 20.

In Fig. 3 is shown a perspective view of the cutter 4 for two different positions I and II of the cutter 4 along its path 22 on the borehole bottom 15. Line 24 indicates the axis of rotation of the drill bit 1. Line 24 also defines the direction of translation of the cutter 4 during percussion action of the drill bit 1. Apart from the cutter 4 having a back-rake angle α as indicated for position I, the cutter 4 also has a side-angle β as indicated for position II. The side-angle β is defined as the angle between the projection of line 16 on plane 17, and said plane defined by the longitudinal axis 24 and the direction of the tangential velocity component 18 of the cutter 4. The angle β can also be defined as a secondary inclination relative to the radial direction of the cutter, the secondary inclination being such that the top surface pushes drill cuttings from the rock formation in radially outward or radially inward direction.

During normal use the drill bit 1 is rotated in the borehole and simultaneously translated along the axis of rotation 24. As the bit 1 rotates the cutter 4 has a circular motion around the geometrical centre of the borehole. Through the impacts of a percussion hammer (not shown) incorporated in the drill string, the cutter 4 is also pushed into the rock formation 15 for short periods of time. As a result the cutter 4 engages the rock formation 15 in its forward, and up-and-down motion. The back-rake angle is such that the combined forward and impact induced movement of the cutter 4 substantially results in compressive stresses in the brittle PDC material only. A back-rake angle of between 30 and 90 degrees is suitable. As a result of the arrangement of cutter 4 with back-rake angle α, the top surface 14

pushes the rock cuttings in forward direction so that the cuttings are moved away from the location where the cutter 4 is active. Furthermore, as a result of the arrangement of cutter 4 with side angle β, a side force is generated on the formation and the loose rock cuttings. This side force, which is in radial direction of the drill bit 1, pushes the formation/cuttings away from the centre of the hole towards the outside diameter where the cuttings are picked up by the drilling fluid and transported towards the surface. The side-angle can be positive (as shown in Fig. 3) but may also be negative, in which case the cuttings are pushed towards the centre of the hole. For either a positive or a negative side-angle the cutter 4 will have an increased capability of lifting the rock cuttings from the bottom of the hole by having a ploughing action.

Referring to Figs. 4, 5 and 6 there is shown a second embodiment of a drill bit 30 for use in the method of the invention. The drill bit 30 has a bit body 32 provided with a plurality of cutters 34 mutually spaced along the bottom face of the drill bit 30. For the sake of clarity, not each cutter has been given a reference numeral. The bit body 32 is furthermore provided with a number of nozzles 36 and waterways (not shown) for drilling fluid. The cutters 34 are similar in construction to the cutters 4 of the drill bit 1 referred to hereinbefore.

As shown more clearly in Fig. 5, the cutters 34 are arranged in a number of cutter rows A, B, C which are arranged at mutually different axial positions on the bit body 32 so as to form a stepped arrangement.

In Fig. 6 are shown two adjacent cutters 34A, 34B of respective rows A and B. Furthermore is shown a portion of the rock material of the borehole bottom 15 as cut

with the cutters 34A, 34B. Line 36 indicates a plane along which a portion 37 of the rock material is sheared off. For the purpose of clarity the bit body 32 is not shown in Fig. 6.

During normal use of the drill bit 30, each cutter 34 of a lower row removes rock material which is supporting rock material attacked by an adjacent cutter 34 of a higher row. Fore example, as shown more clearly in Fig. 6, cutter 34A of row A removes rock material which supports rock material attacked by cutter 34B of row B. Through this combined action the rock material 37 below cutter 34B is more sheared-off along line 36. As a result the overall cutting efficiency increases.

In Figs. 7, 8 and 9 is shown a cutter 40 of a drill bit (not shown) for use in the method of the invention. The cutter 40 is similar in construction to cutter 4 of the embodiment of Fig. 1, and has a shank 42 of Tungsten Carbide and a top layer 44 of a PDC material. The side-angle β of the cutter 40 is such that a V-shaped groove 46 is cut by the cutter 40 in the borehole bottom 15. In a first arrangement (Fig. 8), the cutter has a positive side angle β and zero back-rake angle α. In a second arrangement (Fig. 9), the cutter has a positive side angle β and a positive back-rake angle α. In Figs. 8 and 9 the direction of movement of the cutter 40 is indicated by arrow 47.

During normal use of the cutter 40, the drill bit to which the cutter pertains is rotated and simultaneously translated in a percussion mode whereby the cutter 40 pushes the rock formation at the borehole bottom 15 radially outwards. Such action enhances the cutting action of the cutter 40 and also facilitates the removal

of rock cuttings from the bottom of the hole by pushing the cuttings towards the outward border of the hole where they are ultimately removed by the drilling fluid.

In Fig. 10A is shown a third embodiment of a drill bit 50 for use in the method of the invention. The drill bit 50 has a bit body 52 provided with a plurality of cutters 54 mutually spaced along the bottom face of the drill bit 50. For the sake of clarity, not each cutter has been indicated by a reference numeral. The bit body 52 is furthermore provided with a number of nozzles (not shown) and waterways (not shown) for drilling fluid. The cutters 54, which are similar in construction to the cutters 4 of the drill bit 1 referred to hereinbefore, are arranged in spiralling rows D, E, F and G. The cutters 54 of a particular spiralling row are set at an increasing or decreasing height. Through this setting the cutters 54 operate in a fashion similar to conventional PDC bits, except that the cutting action is additionally upwards/downwards instead of rotational only. As for a conventional PDC bit the cutting depth of an individual cutter 54 is substantially less than its diameter. The force required to make the cut is delivered by a combination of weight on bit (WOB) from the drill string and the percussive downward blows from the percussion hammer.

In Fig. 10B is shown a stepped borehole bottom profile (in longitudinal section) as drilled with the drill bit 50.

Instead of the side-angle β of the cutter 4 being positive (as indicated in Fig. 3) so that the top surface 14 pushes drill cuttings from the rock formation in radially outward direction, the side-angle β can be

negative so that the top surface 14 pushes drill cuttings from the rock formation in radially inward direction.

Instead of the top surface of the cutter being flat, the cutter can have a hemispherical or other suitable shape.

Instead of the drill bit face having a convex shape (as in Fig. 5) the drill bit face can have a concave shape, or a partly convex and partly concave shape.

CLAIMS

1. A drilling system for drilling a borehole in an earth formation, comprising:

- a drill string having a central longitudinal axis and being provided with a drill bit having a bottom surface including a plurality of cutters arranged so that said bottom surface has an envelope of a stepped profile in radial direction;
- first drive means for rotating the drill bit in the borehole so as to induce a scraping movement of the cutters along the borehole bottom, and
- second drive means for inducing a longitudinal reciprocal movement of the drill bit in the borehole so as to induce the cutters to exert a percussion force to the borehole bottom.

2. The drilling system of claim 1, wherein the cutters are arranged in a plurality of circular rows of mutually different diameters, and wherein the top surfaces of cutters in the same row extend at substantially equal axial positions.

3. The drilling system of claim 1 or 2, wherein the cutters in a first said row and the cutters in a second said row adjacent to the first row, have top surfaces at mutually different axial position.

4. The drilling system of any one of claims 1-3, wherein said bottom surface of the drill bit has a convex shape.

5. The drilling system of any one of claims 1-4, wherein each cutter is a Polycrystalline Diamond Compact (PDC) cutter including a shank made of a base material and a top layer made of a poly-crystalline diamond material.

6. The drilling system of anyone of claims 1-5, wherein the top surface of each cutter has a primary inclination relative to the tangential velocity component of the cutter, the primary inclination being such that the top surface pushes drill cuttings in the direction of rotational movement of the cutter.

7. The drilling system of any one of claims 1-6, wherein the top surface of each cutter has a secondary inclination relative to the radial direction of the cutter, the secondary inclination being such that the top surface pushes drill cuttings from the rock formation in radially outward or radially inward direction.

8. The drilling system of any one of claims 1-7, wherein the cutter has a back-rake angle of less than 90°, wherein the back-rake angle is defined as the angle between the projection of a line perpendicular to said top surface on a plane defined by the longitudinal direction of the drill string and the direction of the tangential velocity component of the cutter, and a plane perpendicular to said longitudinal direction.

9. The drilling system of claim 8, wherein said back-rake is between 30° and 90°.

10. The drilling system of claim 9, wherein the back-rake angle is between 30° and 75°.

11. The drilling system of any one of claims 1-10, wherein the top surface of each cutter is substantially flat.

12. The drilling system of any one of claims 1-11, wherein each cutter has a V-shaped longitudinal section.

13. The drilling system substantially as described hereinbefore, with reference to the drawings.

Fig.1.

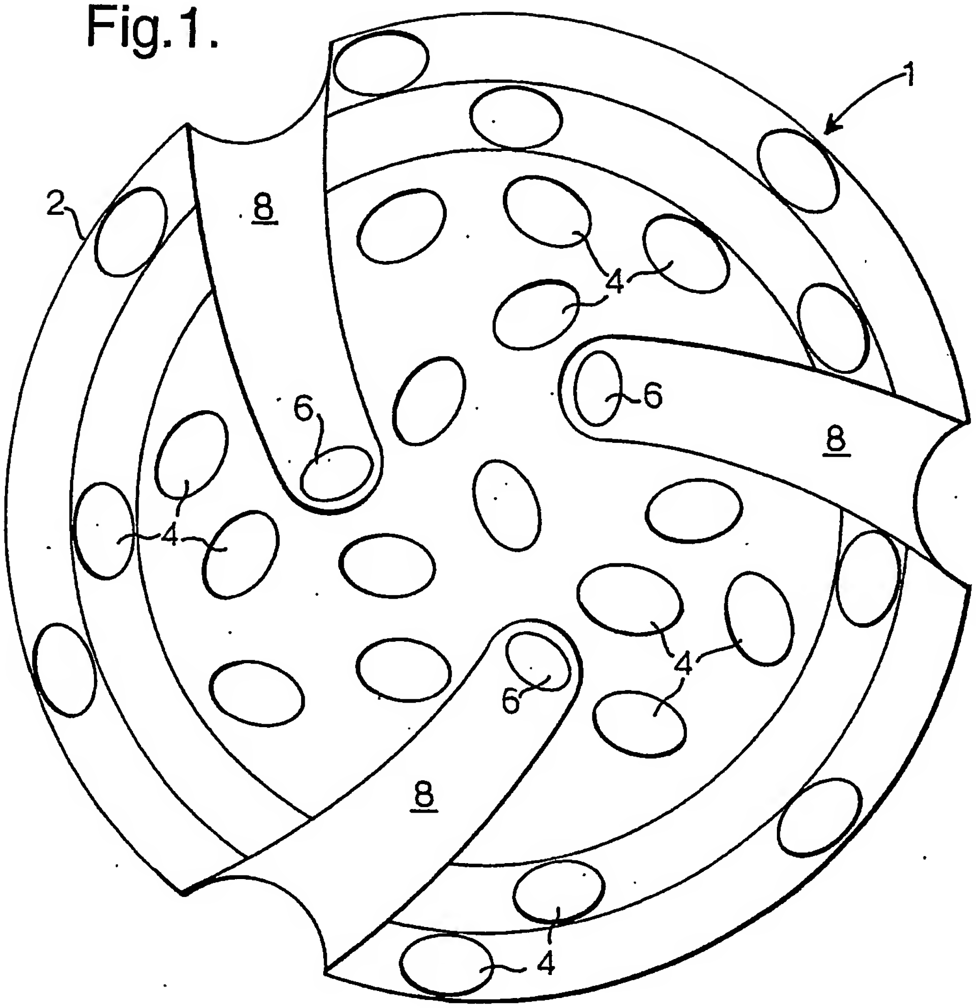


Fig.2.

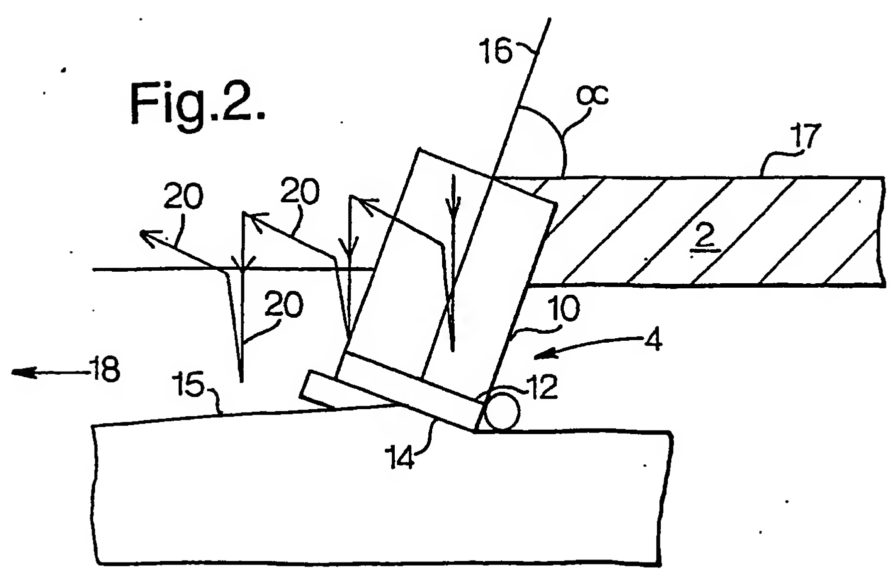
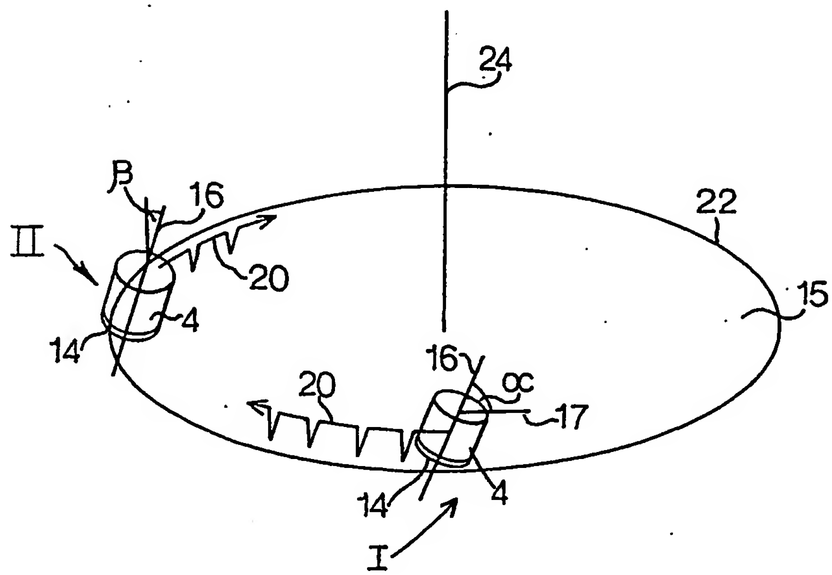


Fig.3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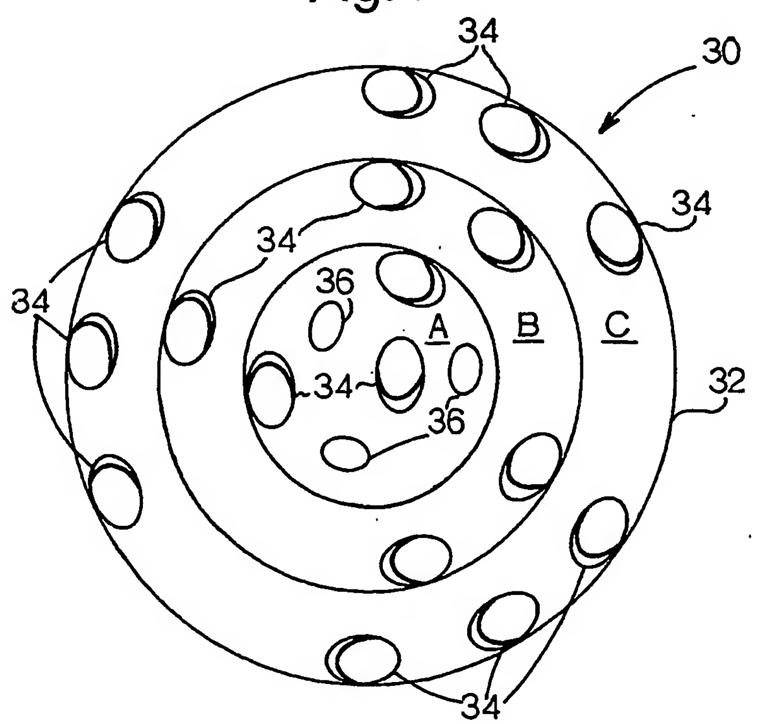
I

Fig.4.


34
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34

Fig.5

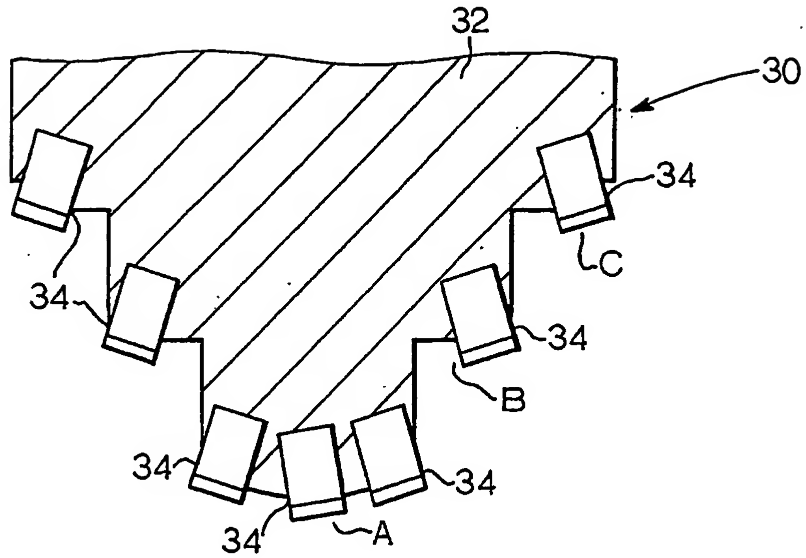


Fig.6

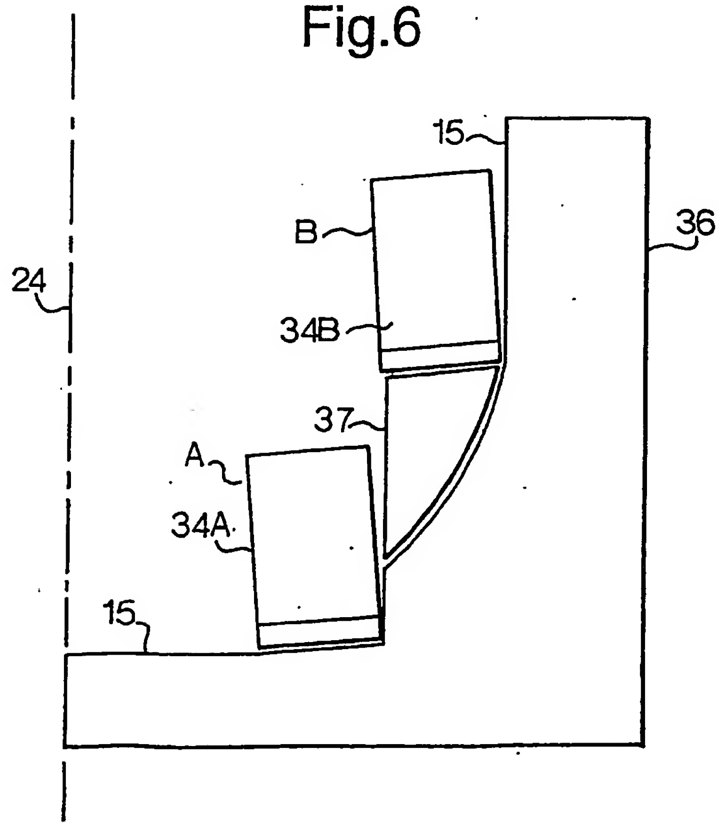


Fig.7.

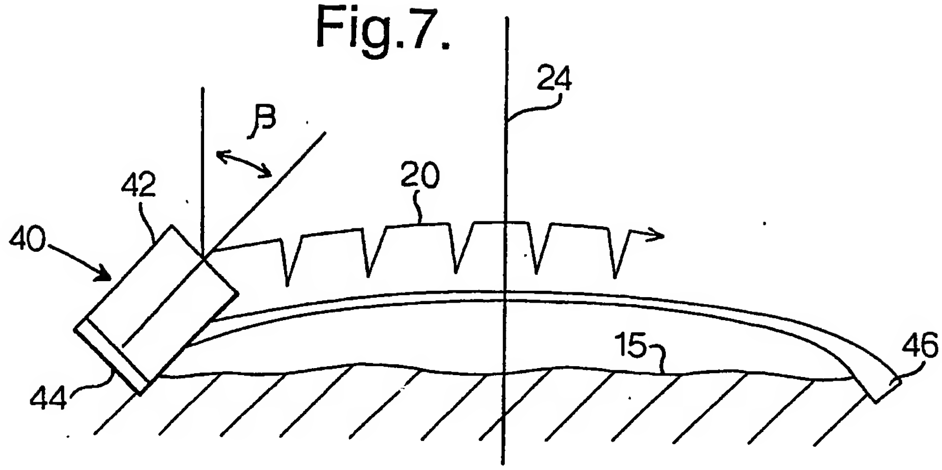


Fig.8.

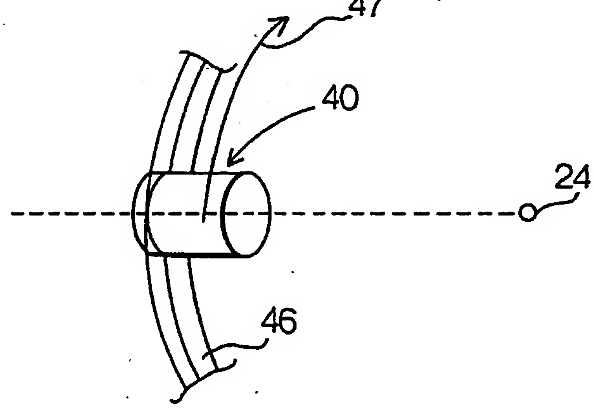


Fig.9.

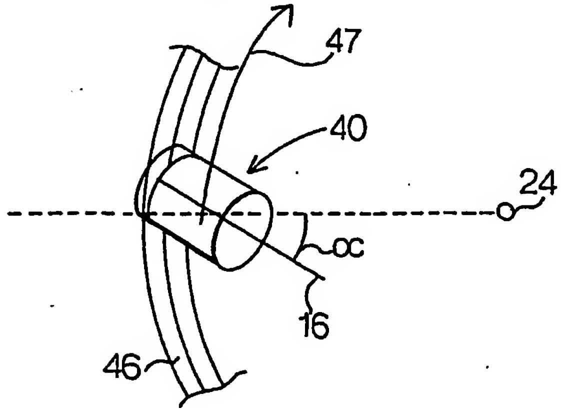


Fig.10 a.

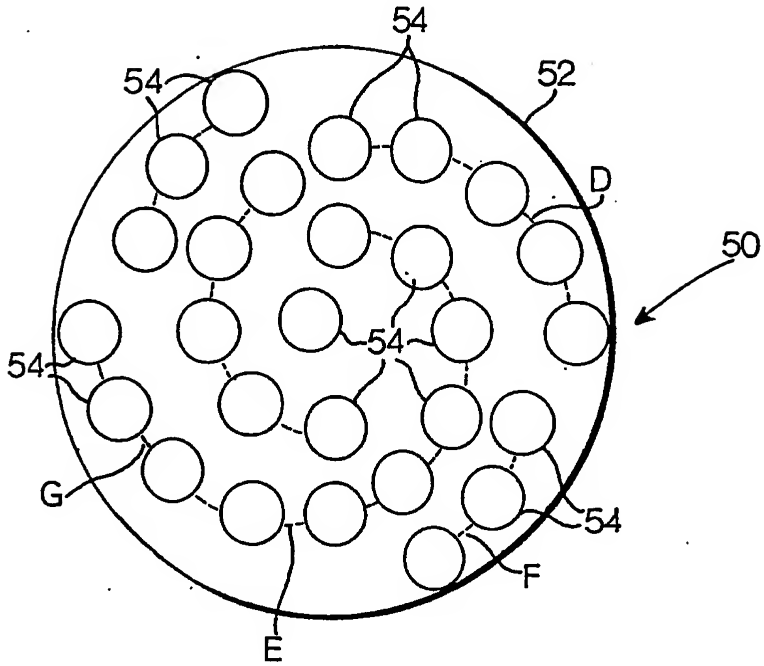
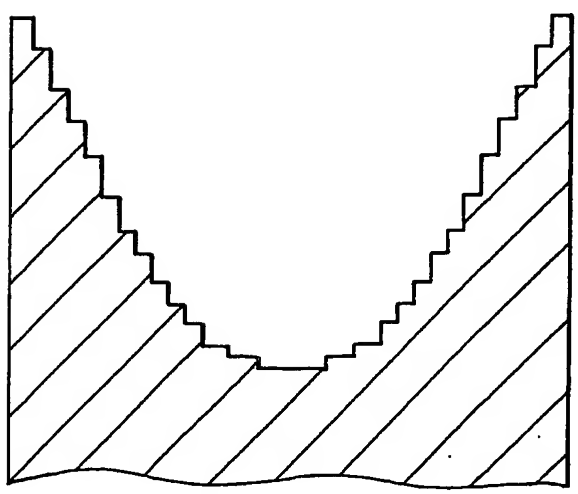


Fig.10b.



INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 02/11064

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 E21B10/36 E21B10/40 E21B10/56 E21B10/46

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2 648 524 A (DIONISOTTI) 11 August 1953 (1953-08-11) column 3, line 25 - line 41; figures 1-14	1-4, 11-13
Y	column 2, line 23 - line 27 ---	5-10
Y	US 4 073 354 A (ROWLEY) 14 February 1978 (1978-02-14) column 4, line 47 - line 50 column 3, line 66 -column 4, line 6 column 4, line 31 - line 34 ---	5-8
Y	US 6 253 864 B1 (HALL) 3 July 2001 (2001-07-03) column 7, line 36 - line 40 claims 10,11 column 7, line 5 - line 40 ---	9,10
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
29 January 2003	05/02/2003

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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